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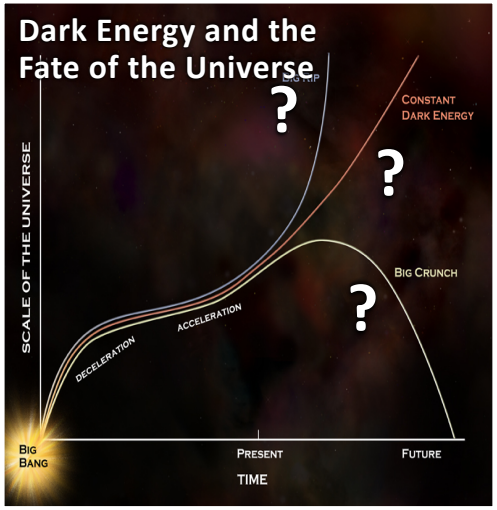
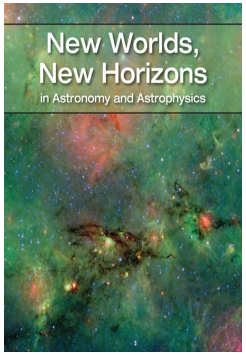
Jet Propulsion Laboratory Exoplanet Science Intiative symposium

March 26, 2018

DIRECT IMAGING OF EXOPLANETARY SYSTEMS WITH WFIRST CORONAGRAPH INSTRUMENT (CGI)

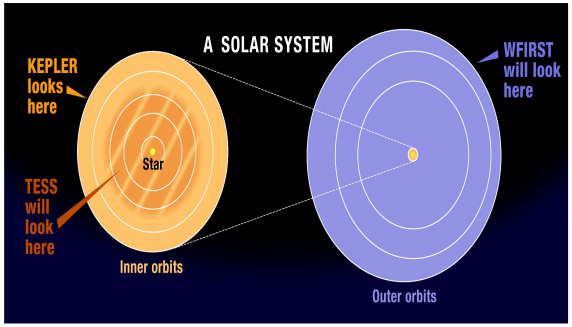
WFIRST Scientific Objectives

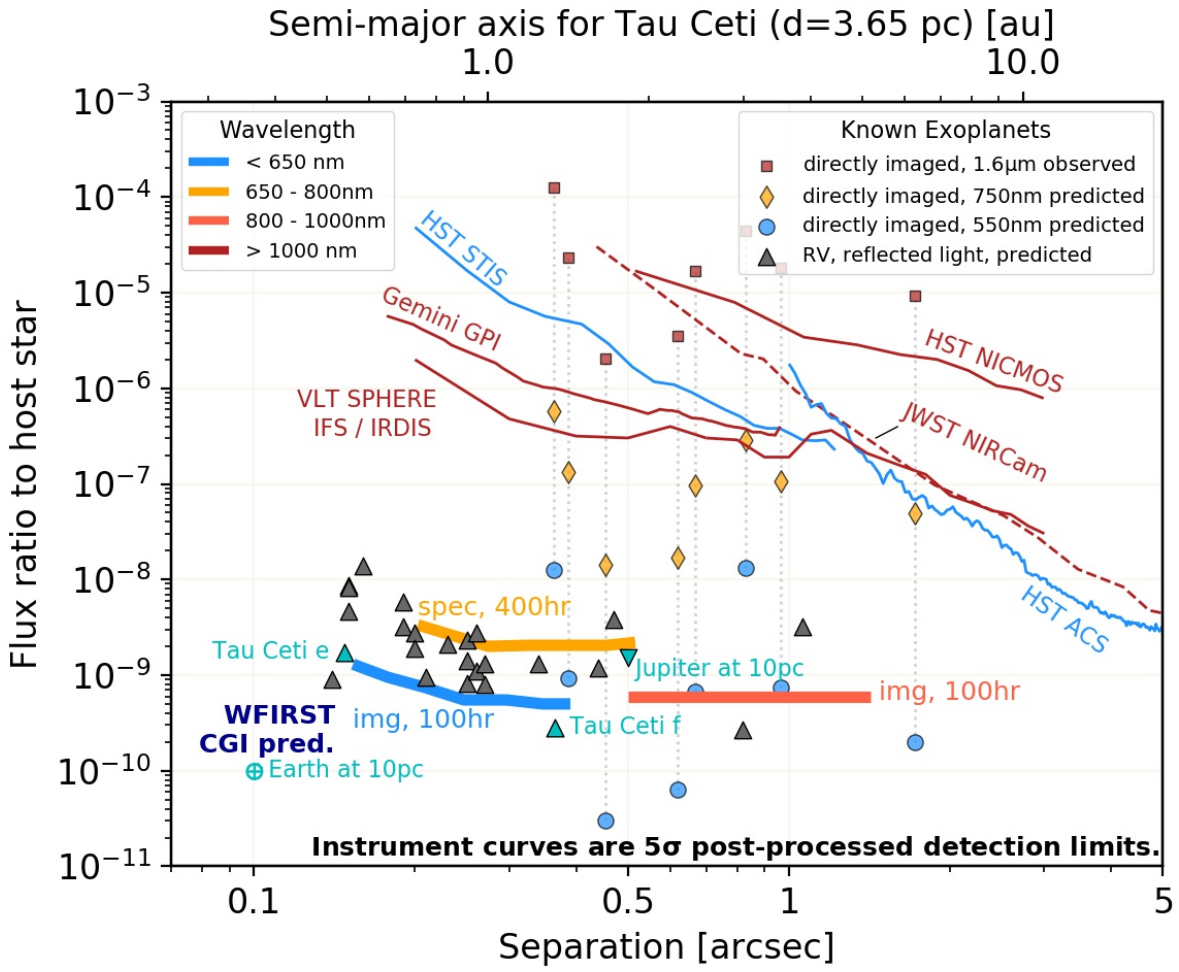




National Academy of Sciences
Astronomy & Astrophysics
Decadal Survey (2010)

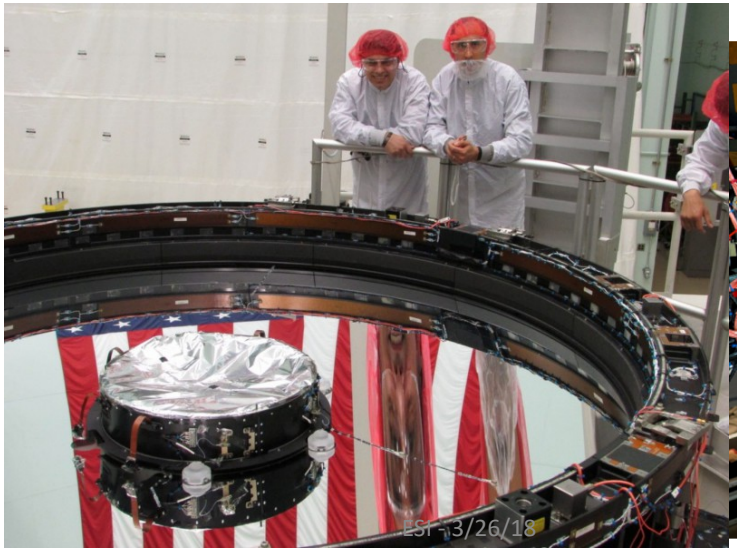
The full distribution of planets around stars




Semi-major axis for Tau Ceti (d=3.65 pc) [au]
1.0
10.0
Wavelength
< 650 nm
650 - 800nm
800 - 1000nm
> 1000 nm
Known Exoplanets
directly imaged, 1.6µm observed
directly imaged, 750nm predicted
directly imaged, 550nm predicted
RV, reflected light, predicted
HST STIS
Gemini GPI
VLT SPHERE
IFS / IRDIS
HST NICMOS
JWST NIRCam
HST ACS
spec, 400hr
Tau Ceti e
Jupiter at 10pc
img, 100hr
WFIRST
CGI pred.
img, 100hr
Tau Ceti f
⊕ Earth at 10pc
Instrument curves are 5σ post-processed detection limits.
Flux ratio to host star
Separation [arcsec]
0.1
0.5
1
5

WFIRST-AFTA

- WFIRST uses– AFTA (Astrophysics Focused Telescope Asset)
- AFTA is a repurposed 2.4 m telescope from another government agency
- The AFTA telescope is already built, and sitting in a storage facility

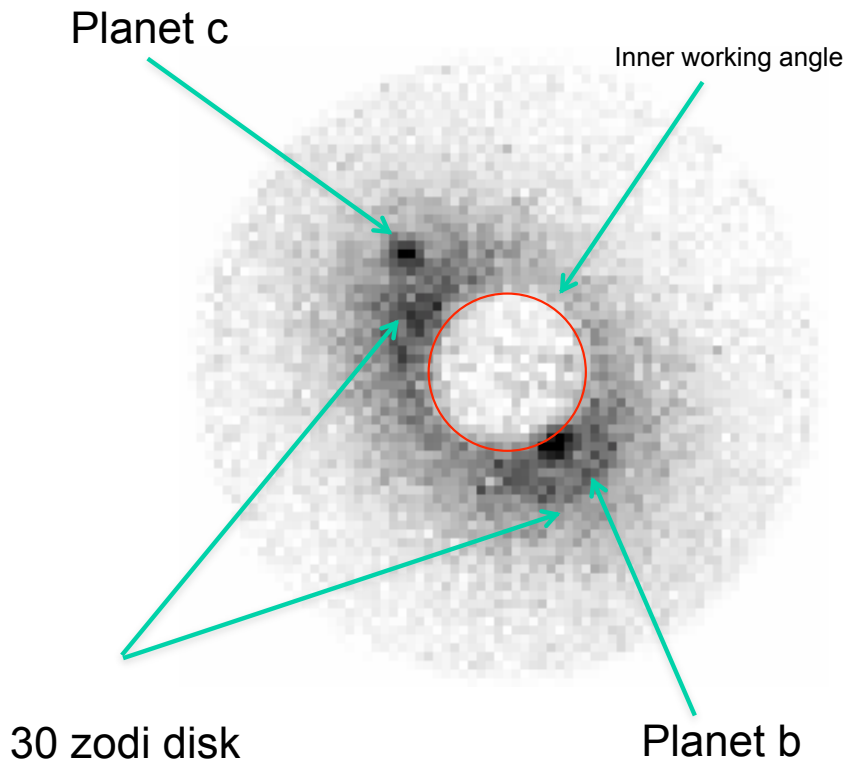


Harris Corporation / TJT Photography

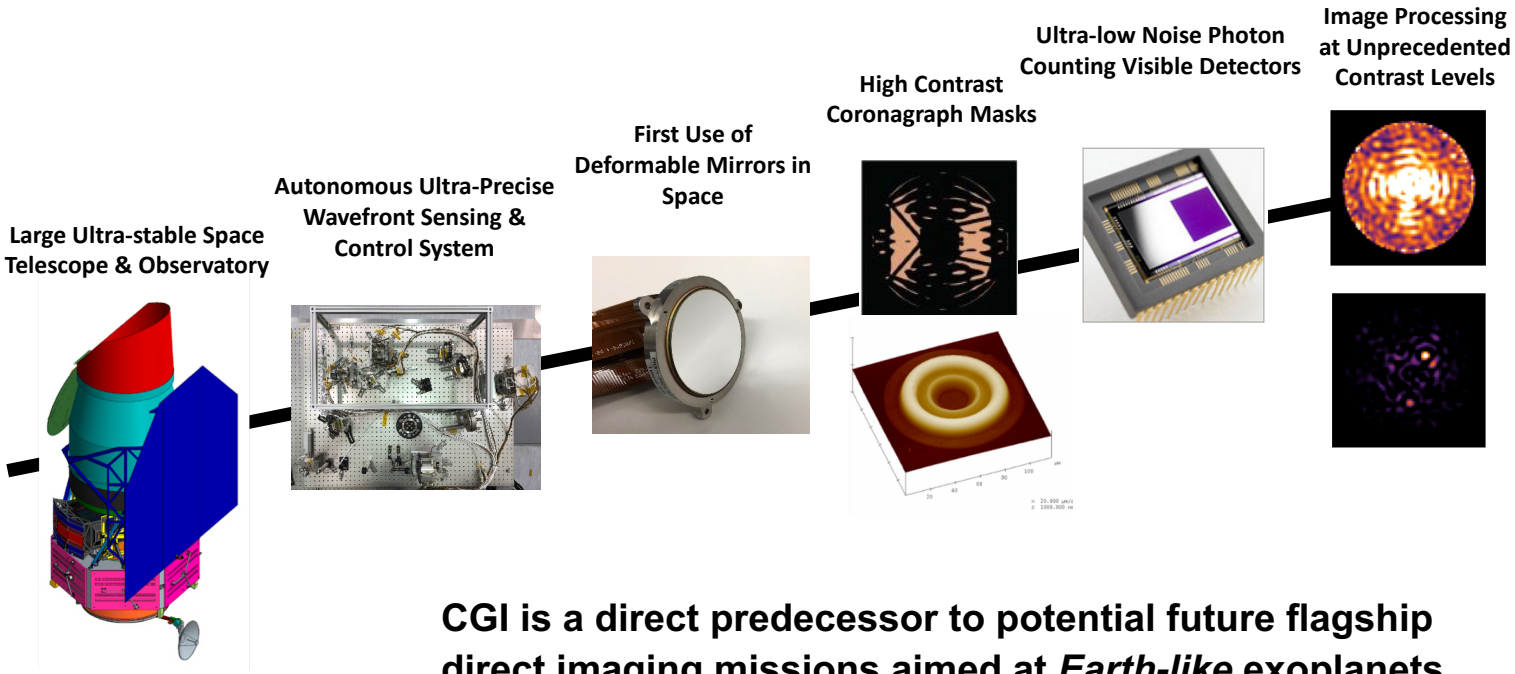
- WFIRST-AFTA includes a coronagraph to image exoplanets
- This was not envisaged by the decadal survey
- Enabled by the 2.4 meter mirror

Coronagraphy

- A coronagraph ‘blocks’ light from a host star, enabling light from an exoplanet to enter the detector
- The contrast between a host star and the planets is large

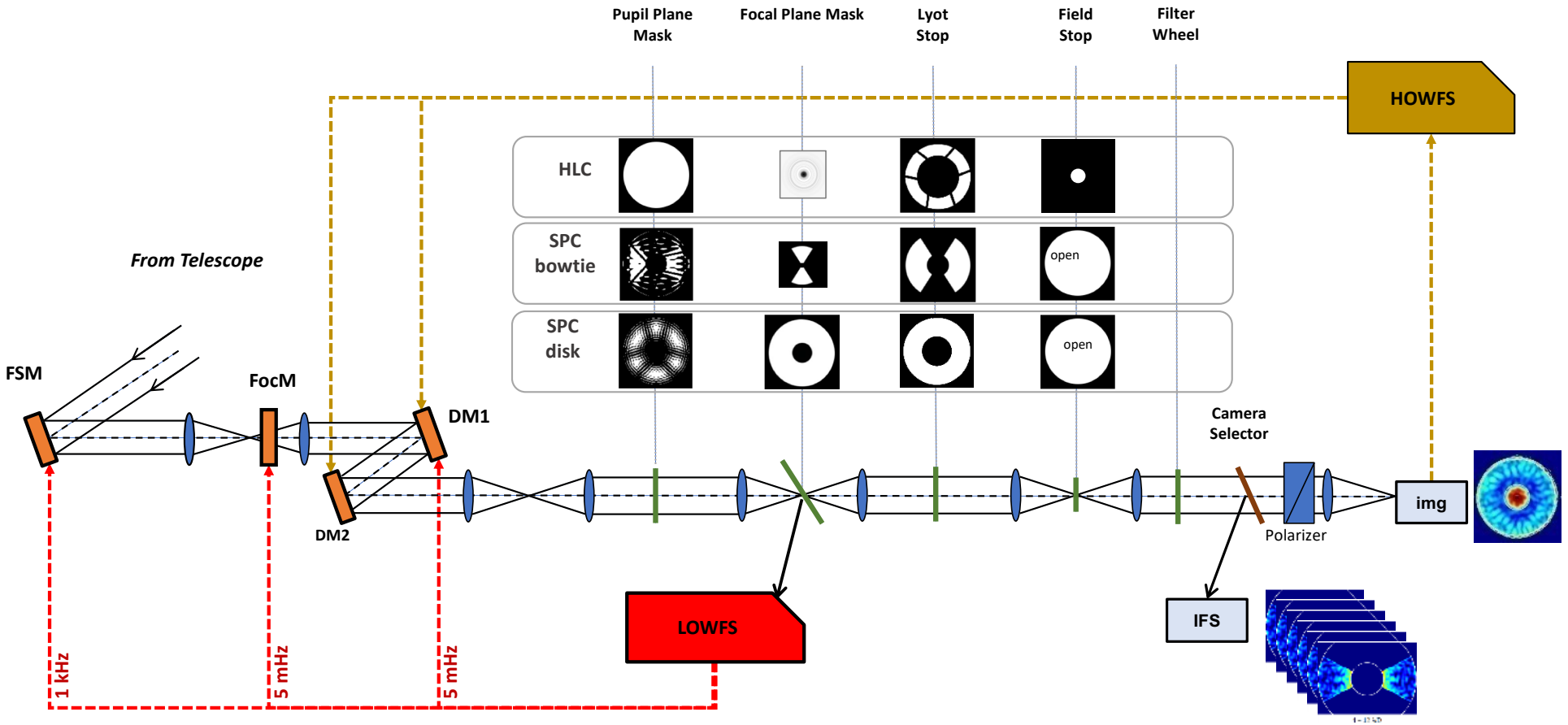


Coronagraph technology development

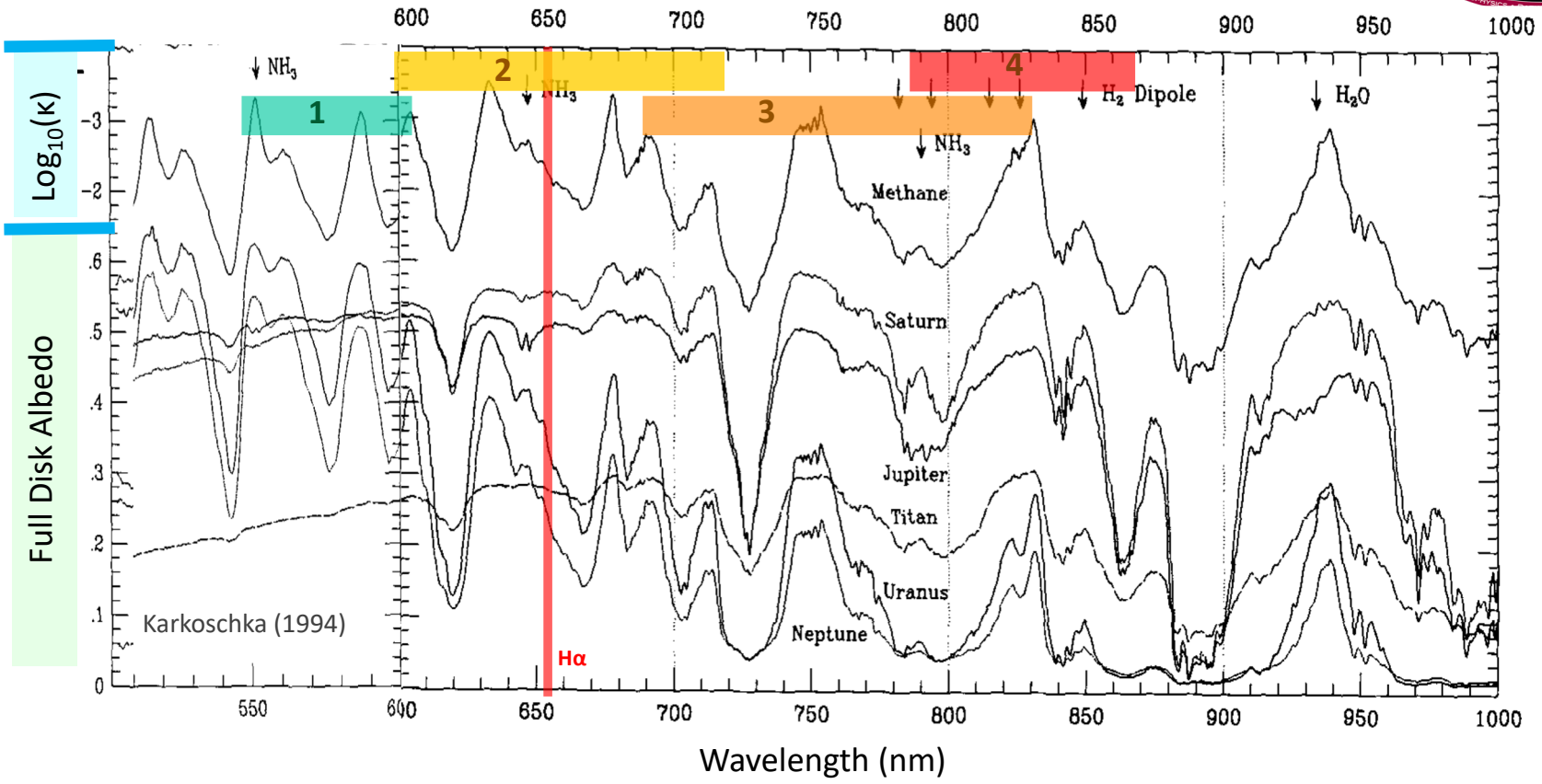


CGI is a direct predecessor to potential future flagship direct imaging missions aimed at *Earth-like* exoplanets (HabEx and LUVOIR)

CGI schematic diagram



CGI Science Filters



λ_1=575 nm, 10% (annular, 3-9 λ/D)
λ_2=660 nm, 18% (bow-tie / IFS, 3-9 λ/D)
λ_3=760 nm, 18% (bow-tie / IFS, 3-9 λ/D)
λ_4=825 nm, 10% (annular, 3-19 λ/D)

CGI Modes Table

CGI Filters	λ_{center} (nm)	BW	Channel	Masks	Working Angle	Can use w/ linear polarizers	Starlight Suppression Region	Tested before launch?
1	575	10%	Imager	HLC	3-9 λ/D	Y	360°	Y
2	660	18%	IFS	SPC	3-9 λ/D		130°	
2	660	18%	Imager	SPC	3-9 λ/D	Y	130°	
3	760	18%	IFS	SPC	3-9 λ/D		130°	Y
3	760	18%	Imager	SPC	3-9 λ/D	Y	130°	
4	825	10%	Imager	HLC	3-9 λ/D	Y	360°	
4	825	10%	IFS	HLC	3-9 λ/D		360°	
4	825	10%	IFS	SPC disk	6.5λ/D - 0.8”		360°	
4	825	10%	Imager	SPC disk	6.5-20 λ/D	Y	360°	Y

λ_1=575 nm, 10% (annular, 3-9 λ/D)
λ_2=660 nm, 18% (bow-tie / IFS, 3-9 λ/D)
λ_3=760 nm, 18% (bow-tie / IFS, 3-9 λ/D)
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Powers of 10

- Current best coronagraphs reach a contrast ratio of 10^{6-7}
- WFIRST CGI performance predictions ~ 10^{9}
- All technological milestones have been hit ahead of schedule and contrasts of 10^{8-9} has been shown in lab
- WFIRST will test two different types of coronagraphs for both spectroscopy (shaped pupil) and photometry (hybrid Lyot)
- What we need for direct imaging of an exo-Earth to show biomarkers is probably 10^{10}
- The Astro 2020 Decadal Survey will look at HabEx and LUVOIR, two mission concepts that might be able to do this

Science cases for CGI

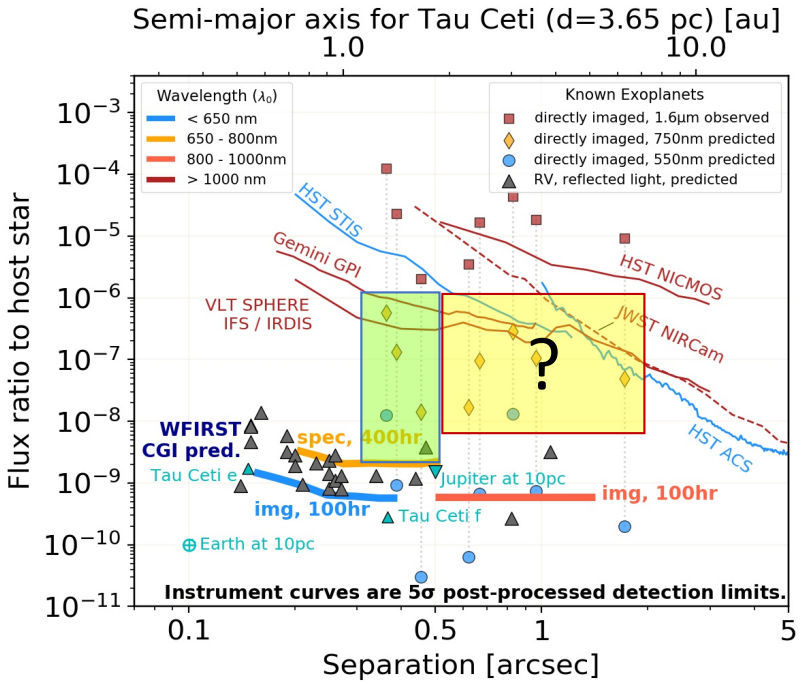
- Spectroscopy of young self-luminous giant planets
- Imaging & Spectroscopy of reflected light giant planets
- Blind search for gas giants (reflected & emitted light)

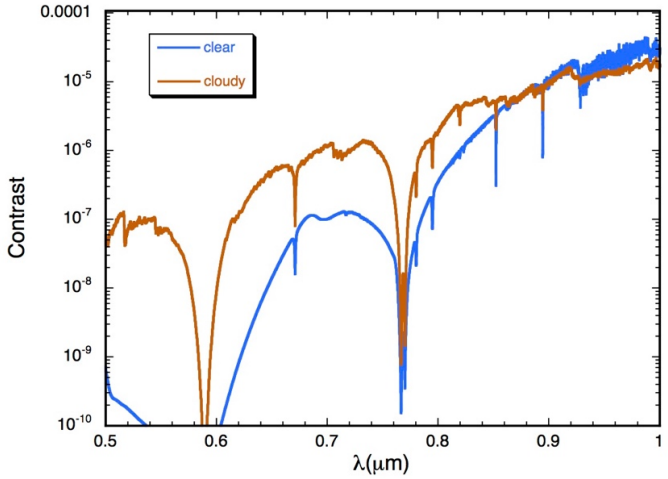
- Imaging and spectroscopy of disks
  - Debris
  - Protoplanetary
  - Exozodi

- Download at http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_180659 "View submitted whitepapers"

Spectra of self-luminous planets

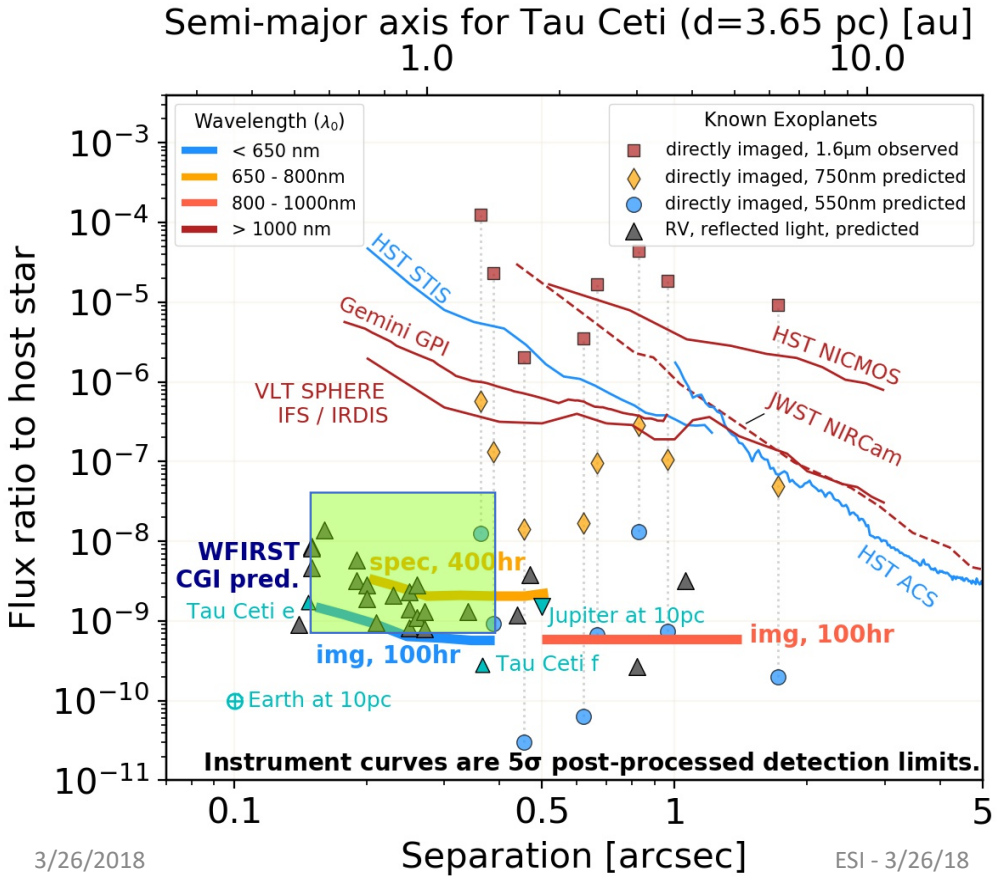
Beta Pic b, HR 8799 e, 51 Eri b

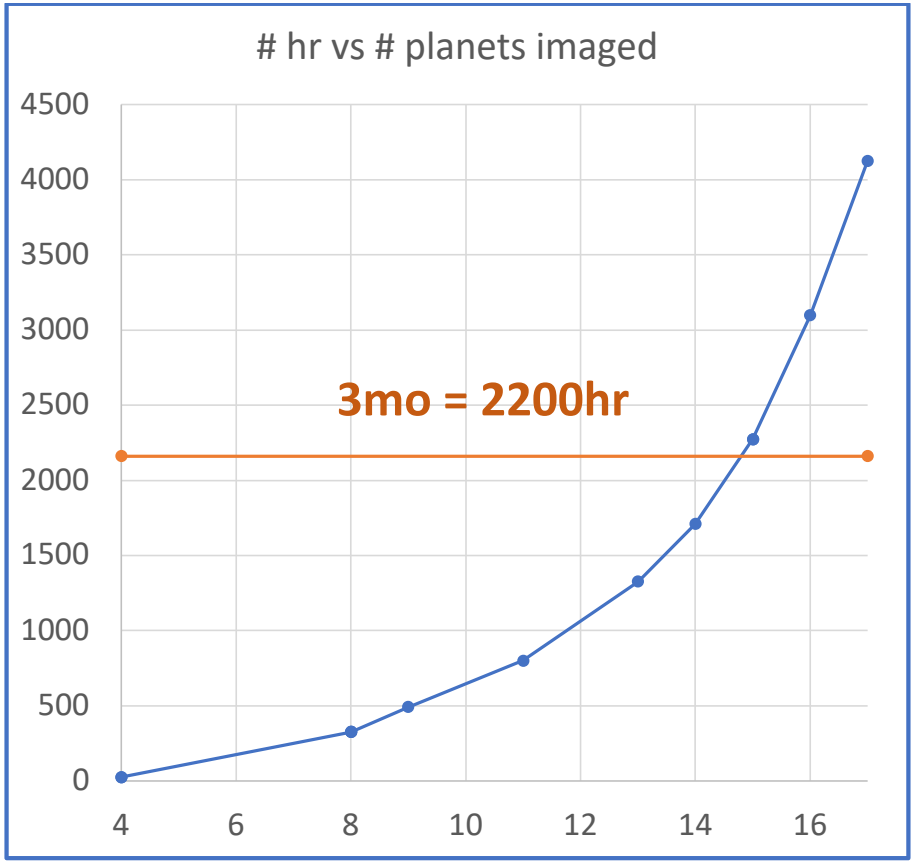




- New models needed!
- Others possible with IFS + SPC donut?
- Halpha accretion?

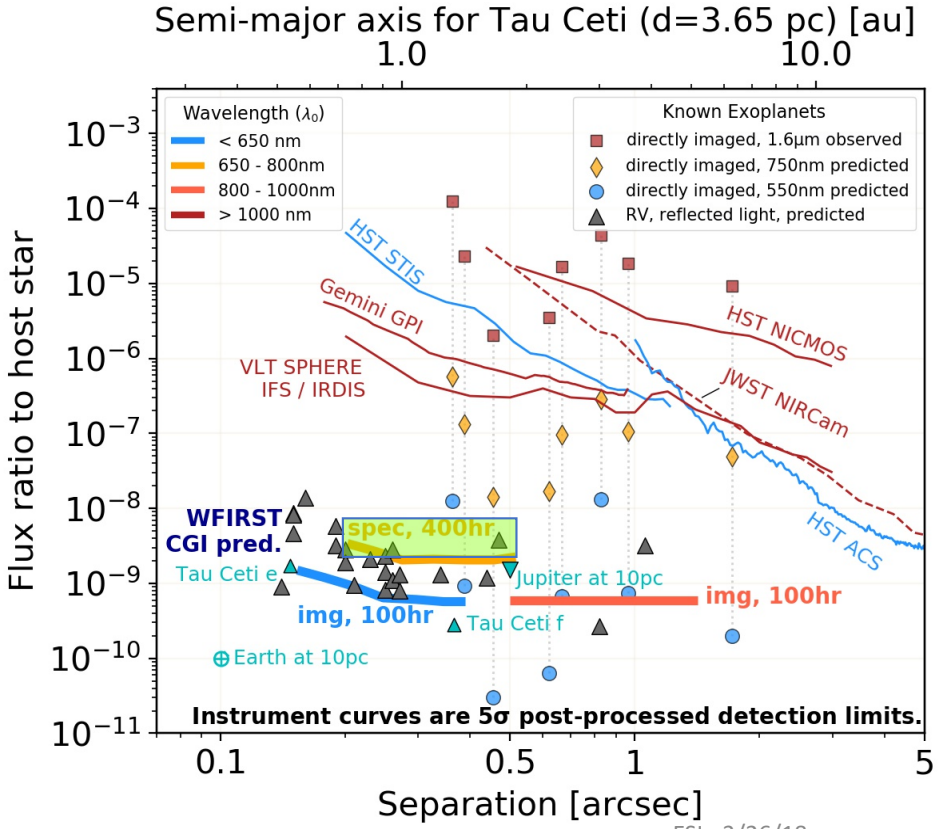
Reflected light imaging of known RV planets





B. Nemati exposure time calculator

Reflected light spectroscopy of RV planets



- Eps Eri ~ 15hr
- 47 Uma ~ 510hr
- HD 114614 ~ 1600hr

Blind search: 3 months ~ 10 new planets

Savransky 2016

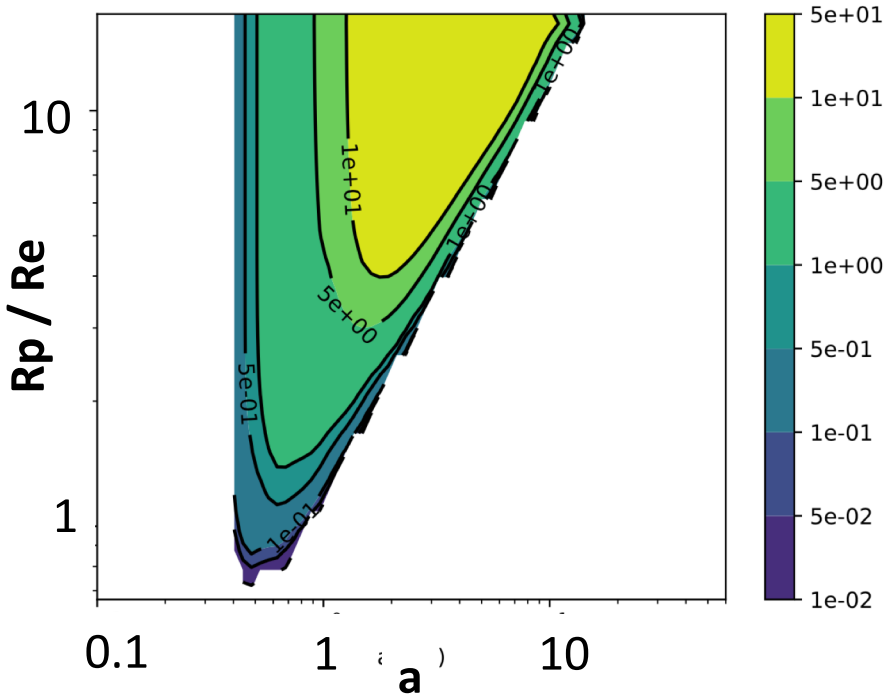
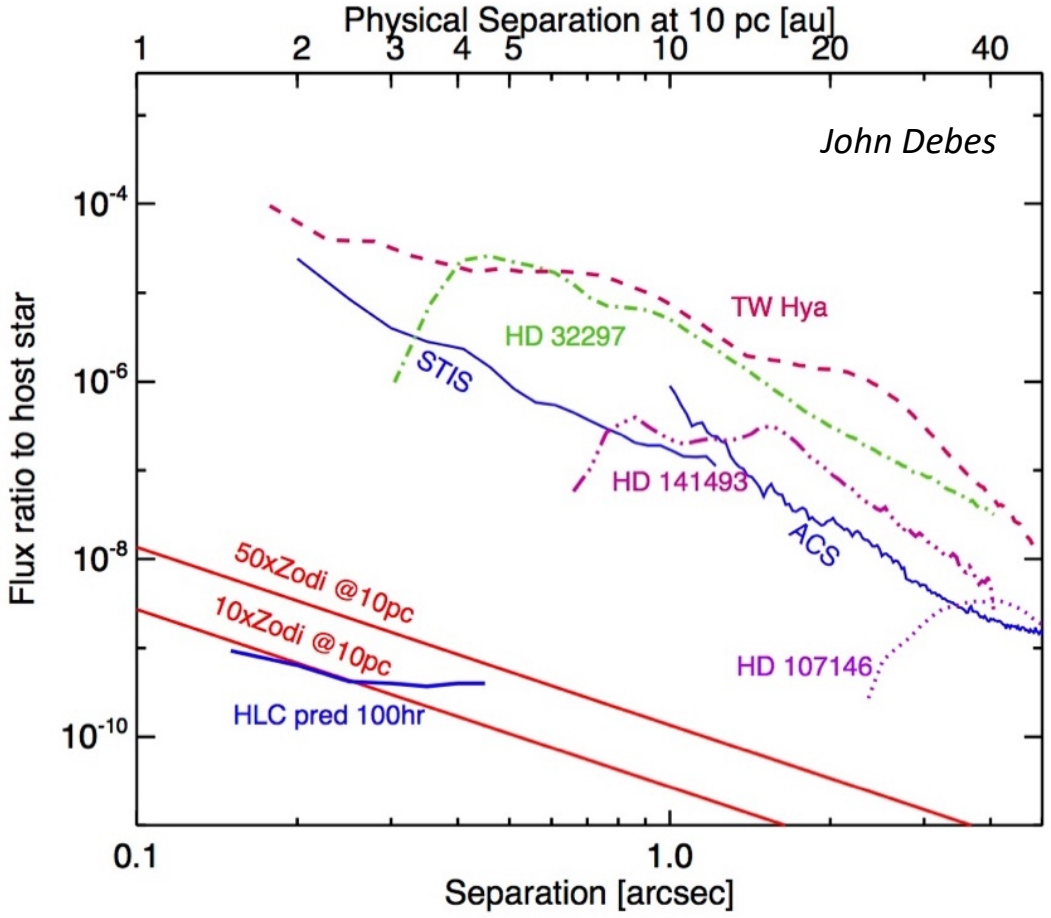


Figure 4: Depth of search (summed completeness assuming one planet per star at each location in the semi-major axis-Radius phase space) for the WFIRST CGI assuming optimal utilization of 3 months of integration time (96 total targets). Giant planets (>5 Earth radii) are found most frequently (>50%) while the CGI is barely sensitive to 2 Earth-radii planets (0.5%). Albedos were assumed to be uniformly 0.2 for planets below 1.4 Earth radii and 0.5 for larger planets.

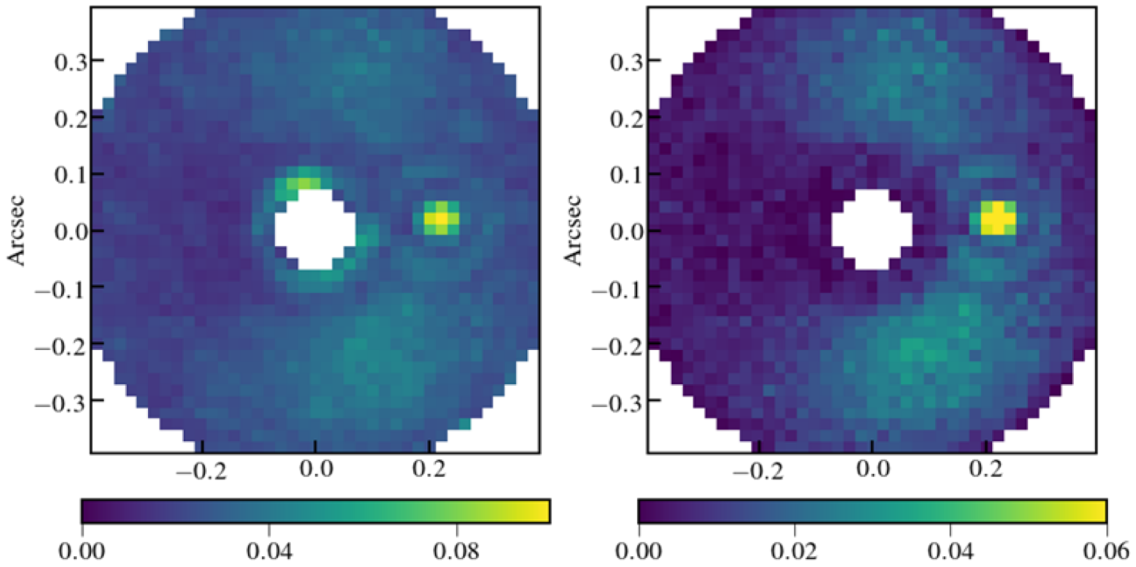
Disk Science

- Known disks guaranteed
- Intermediate disks likely

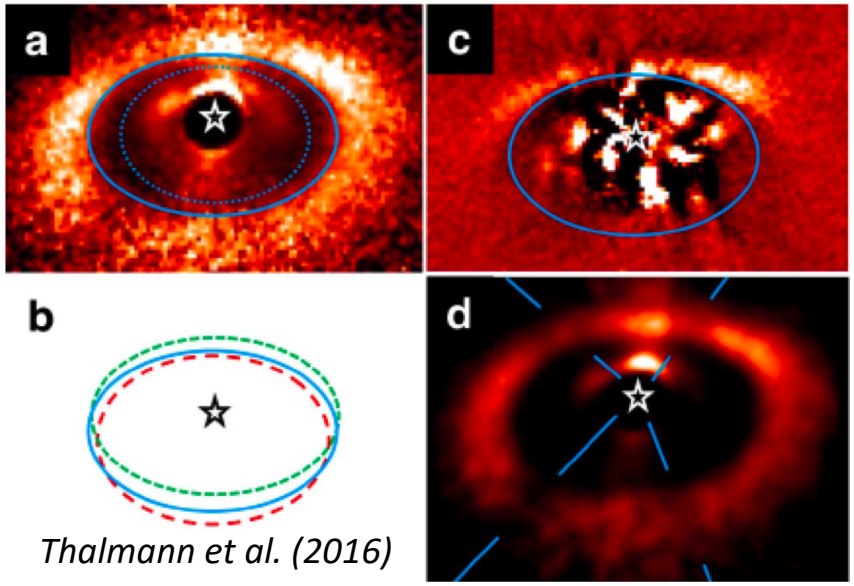


Exozodi “contaminants”

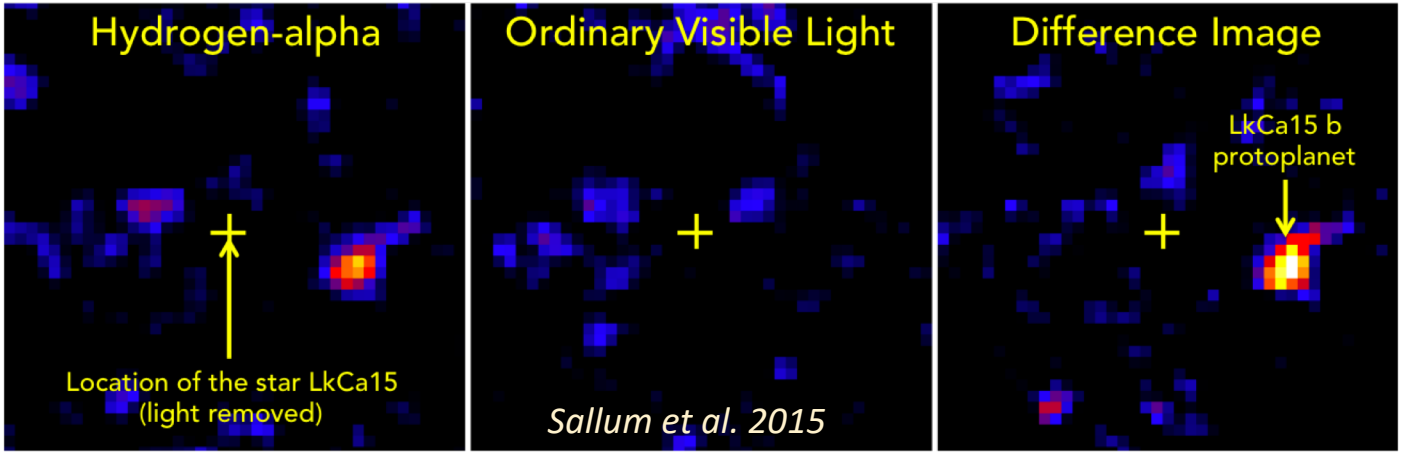
HLC 575 nm imaging. Nearby sunlike star. 10zodi disk & embedded jovian planet located at 1.6 AU. Flux scale is square-root stretch in units of photoelectrons/s. Simulated exposure time is 2.8 h. (Courtesy of M. Rizzo, N. Zimmerman and the “Haystacks” team). Left/Right = image without/WITH PSF subtraction.



Protoplanetary disks & protoplanets



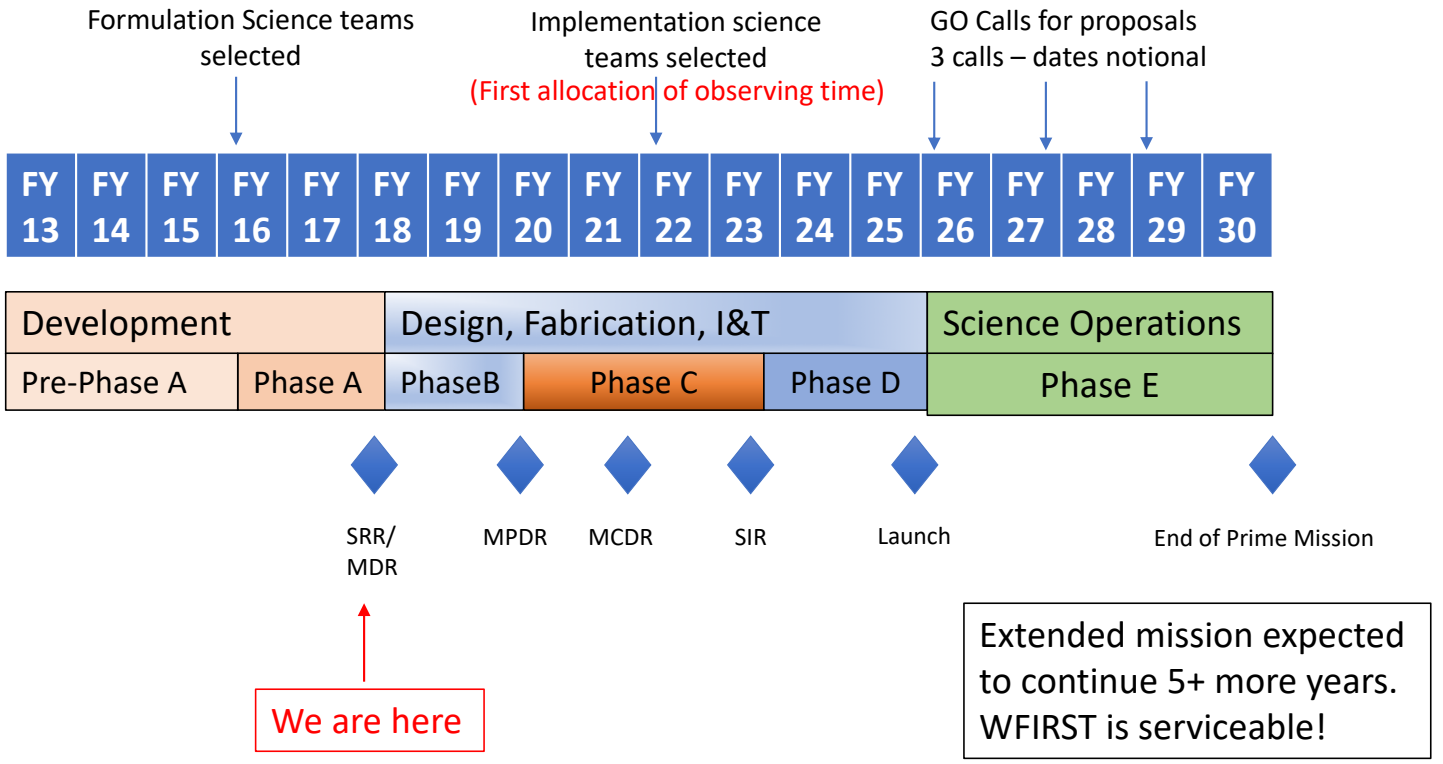
Thalmann et al. (2016)



WFIRST CGI Science Yield vs Instrument Performance: Exo-planetary systems

Science \ Contrast	10^{-9}	3×10^{-9}	10^{-8}	10^{-7}
Cool EGPs optical spectra	Yes (10+)	A few	No	No
Cool EGPs optical Images	Yes	Yes	Possibly	No
Young EGPs optical spectra	Yes	Yes	Yes	Some
Young EGPs optical images	Yes	Yes	Yes	Some
Exo-Zodi Disks optical images	10 zodis	40 zodis	~100 zodis	1000 zodis

Project Schedule



Opportunities with WFIRST

- 25% Guest Observer in 5 year prime mission
- ~100% GO in extended mission
- Guest Investigator calls throughout mission
- All prime survey science teams will be competed in ~2021
- 2020 Decadal Survey will consider a Probe class Starshade


WIDE-FIELD INFRARED SURVEY TELESCOPE
WFIRST
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

Formulation Science Working Group

Jeff Kruk GSFC Project Scientist, **Chair**
Jeremy Kasdin Princeton U. CGI Adjutant Scientist, Co-Chair
David Spergel Princeton U. WFI Adjutant Scientist, Co-Chair

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Ryan Foley U. Illinois Supernovae
Scott Gaudi Ohio State U. Microlensing
Jason Kalirai Johns Hopkins U. GO, Milky Way Science
Bruce Macintosh Stanford U. Coronagraph
Saul Perlmutter LBNL Supernovae
James Rhoads Arizona State U. GO, Cosmic Dawn
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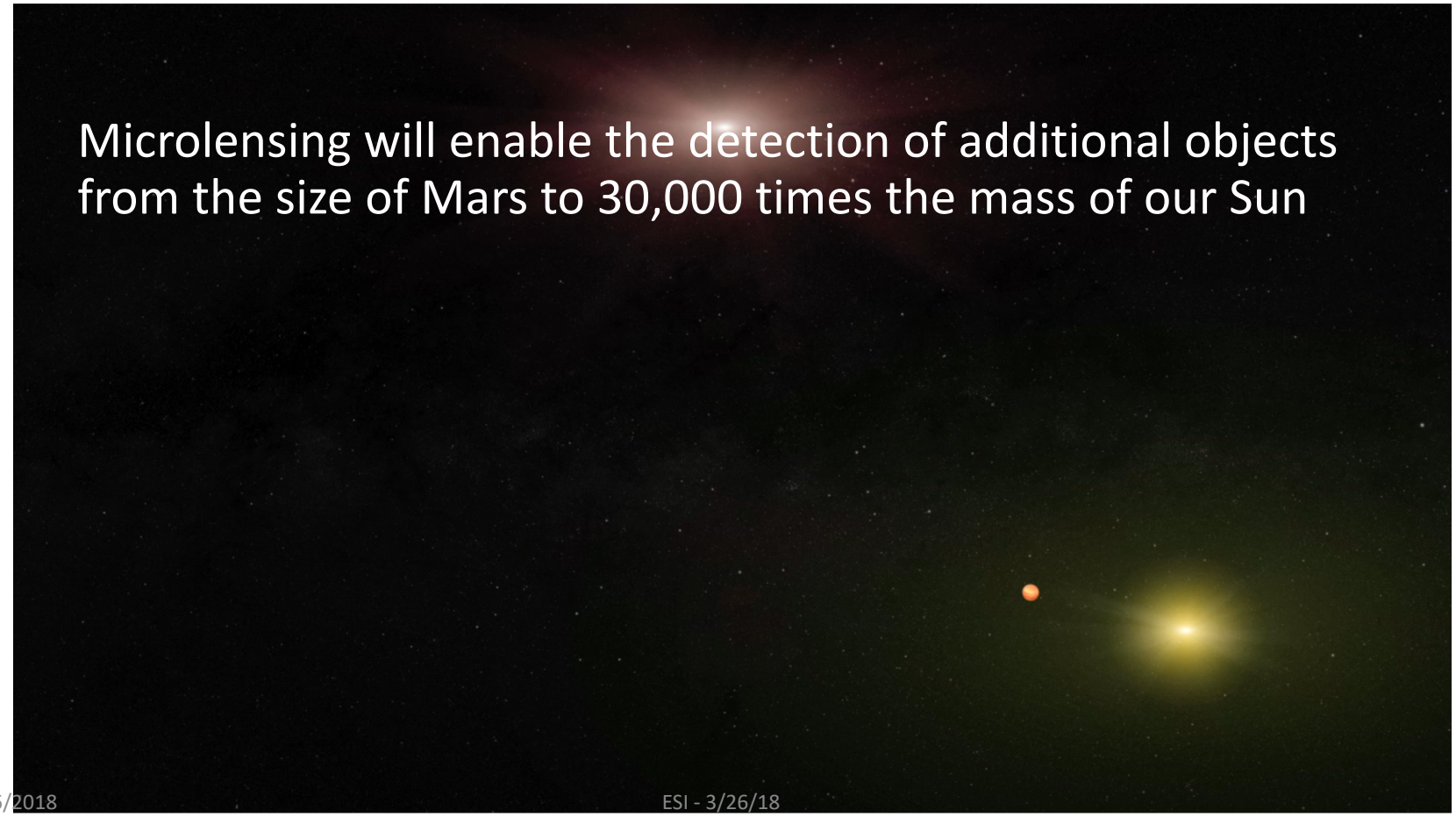
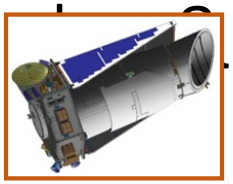
Jean Dupuis CSA Representative
Thomas Henning ESA Representative
Toru Yamada JAXA Representative

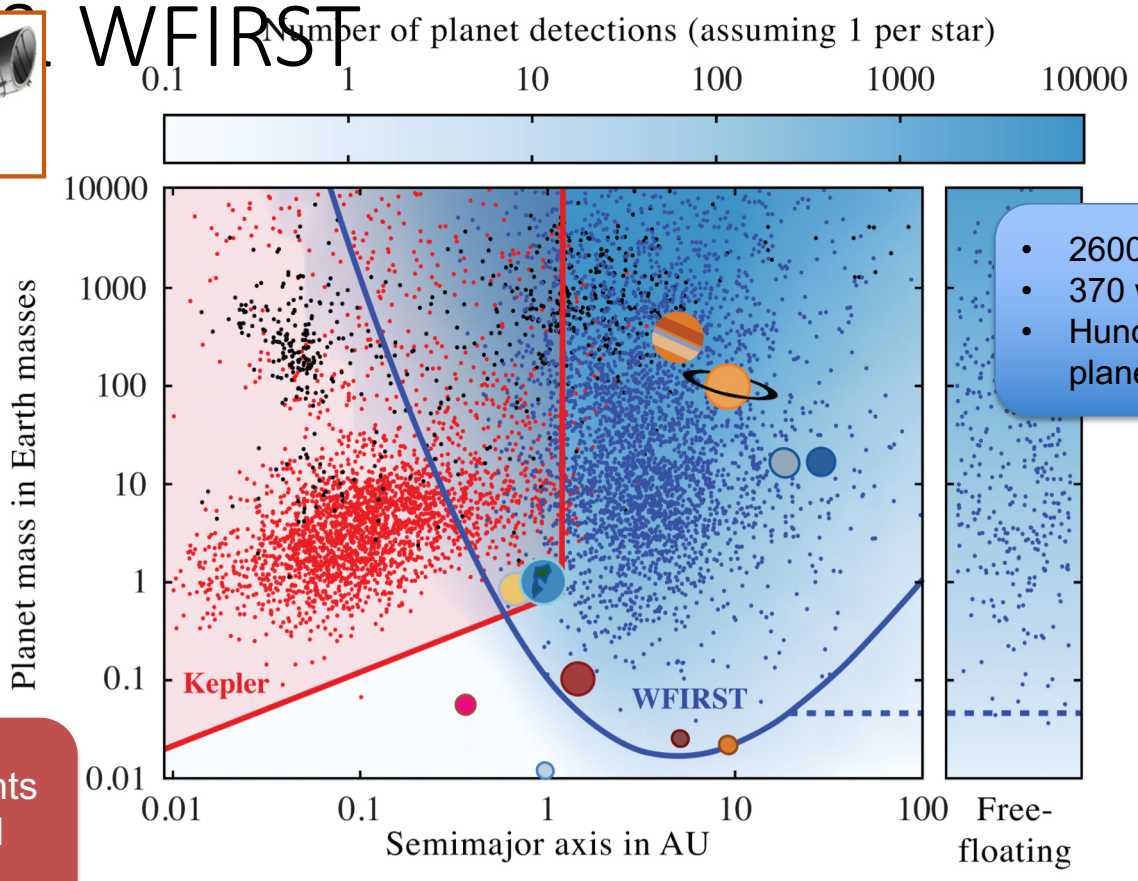
Coronagraphy is Challenging

Microlensing



Exoplanet Surveys
Kepler & WFIRST





- 2600 planet detections.
- 370 with Earth mass and below.
- Hundreds of free-floating planets.

WFIRST complements Kepler, TESS, and PLATO.

M. Penny (OSU)

WFIRST Complements Kepler